9 / Declaration
10.15.02
C. Moore

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re United States Patent Application of:		**Docket No.:**	**2771-410 (7483)**
Applicant:	**Joan M. REDWING, et al.**	**Examiner:**	**Wai Sing Louie**
Application No.:	**09/633,598**	**Art Unit:**	**2814**
Date Filed:	**August 7, 2000**	**Customer No.:**	**25559**
Title:	**INDIUM GALLIUM NITRIDE CHANNEL HIGH ELECTRON MOBILITY TRANSISTORS, AND METHOD OF MAKING THE SAME**	**Confirmation No.:**	**2700**

EXPRESS MAIL CERTIFICATE

I hereby certify that I am mailing the attached documents to the Commissioner for Patents on the date specified, in an envelope addressed to the Commissioner for Patents, Washington, DC 20231, and Express Mailed under the provisions of 37 CFR 1.10.

Katrina Holland
Katrina Holland

October 7, 2002
Date

EV 059304038 US
Express Mail Label Number

DECLARATION UNDER 37 CFR §1.131 OF JOAN M. REDWING AND EDWIN L. PINER IN U.S. PATENT APPLICATION NO. 09/633,598

Commissioner for Patents
Washington, DC 20231

Sir:

JOAN M. REDWING and **EDWIN L. PINER**, hereby declare:

1. That they are the named inventors for United States Patent Application No. 09/633,598 filed August 7, 2000 in the United States Patent and Trademark Office in their names for **"INDIUM GALLIUM NITRIDE CHANNEL HIGH ELECTRON MOBILITY TRANSISTORS, AND METHOD OF MAKING THE SAME"** (hereafter referred to as the "Application") which discloses and claims a gallium nitride-based high electron mobility transistor device, comprising an at least partially relaxed channel layer comprising an InGaN alloy (the "Invention").

2. That they are aware that the claims pending in the Application have been rejected in a June 5, 2002 Office Action of the U.S. Patent and Trademark Office on the basis, *inter alia*, of cited references which have been applied against the claims, and that they have reviewed and are familiar with the pending claims, Office Action and cited references.

3. That the references cited in the June 5, 2002 Office Action include:

   Maeda et al., Japanese Patent Publication JP 11-274474 (hereafter "Maeda") published October 8, 1999;

   Yoshida, Japanese Patent Publication JP 11-261053 (hereafter "Yoshida") published September 24, 1999;

   Nagahama et al., U.S. Patent 6,172,382 (hereafter "Nagahama") having a U.S. filing date of January 9, 1998; and

   Kawai et al., U.S. Patent 5,929,467 (hereafter "Kawai") having a U.S. filing date of December 3, 1997.

4. That attached hereto in Appendix A of this Affidavit is a true and exact copy of their Invention Disclosure entitled "InGaN Channel HEMTs," which they prepared and executed in the scope of their employment by Advanced Technology Materials, Inc., 7

Commerce Drive, Danbury, Connecticut 06810, the assignee of the Application and Invention, and that such Invention Disclosure describes the Invention, and on page 6 thereof states that

> **"the idea of using InGaN in the channel layer of a GaN-based HEMT was included in a phase I SBIR submitted to BMDO in January, 1997. The sections on InGaN in that proposal were marked as proprietary."**

in reference to a Phase I proposal submitted under the Small Business Innovation Research (SBIR) Program of the United States Government by their assignee, Advanced Technology Materials, Inc., to the United States Ballistic Missile Defense Organization (BMDO) as the funding agency (SBIR Proposal).

5. That attached hereto in Appendix B of this Affidavit is a true and exact copy of correspondence dated February 25, 1997 from Sharon A. Gibbons, SBIR Program Manager, Department of the Air Force, to their assignee, Advanced Technology Materials, Inc., concerning the SBIR Proposal, and containing the following text:

> **"Please be advised that your proposal, entitled "InGaN Channel MODFET for Microwave Power Applications," submitted to the Avionics Directorate in response to Topic No. AF97-124 of the subject solicitation, has not been selected for funding."**

6. That subsequent to the refusal of the SBIR Proposal for funding of work relevant to the Invention, their assignee, Advanced Technology Materials, Inc., in the next following SBIR funding cycle, in 1998, submitted another proposal for funding of work relevant to the Invention (SBIR Proposal II).

7. That SBIR Proposal II was accepted and resulted in an award by the U.S. Army Space and Missile Defense Command of U.S. Government Contract No. DASG60-98-C-0025 to their assignee, Advanced Technology Materials, Inc., for performance of work relevant to the Invention.

8. That attached hereto in Appendix C of this Affidavit is a true and exact copy of page 1 of the Application as filed in the U.S. Patent and Trademark Office on August 7, 2000, containing the following passage:

> **"GOVERNMENT RIGHTS IN INVENTION**
> **The invention was made in the performance of the U.S. Army Space and Missile Defense Command, Contract Number DASG60-98-C-0025. The government has certain rights in the invention."**

9. That the documents of Appendices A and B are offered as evidence that the Invention was conceived at least as early as January, 1997, prior to the October 8, 1999 publication date of the Maeda reference, prior to the September 24, 1999 publication date of the Yoshida reference, prior to the filing date of January 9, 1998 of the Nagahama reference, and prior to the filing date of December 3, 1997 of the Kawai reference.

10. That the document of Appendix C is offered as evidence that the Invention was practiced in the performance of the 1998 U.S. Army Space and Missile Defense Command Contract Number DASG60-98-C-0025, and as evidence of continuing diligence from our conception of the Invention to such practice of the Invention in the performance of the 1998 U.S. Army Space and Missile Defense Command Contract Number DASG60-98-C-0025

We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these

statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Joan M. Redwing
Joan M. Redwing

10/3/02
Date

Edwin L. Piner

10/7/02
Date

APPENDIX A

FILE COPY

INVENTION DISCLOSURE

ROI Number 99-27

2771 - 410
(PC 49000)

Short, Descriptive Title **InGaN Channel HEMTs**

(1) State the PROBLEM or DEFICIENCY which is overcome by your invention:

GaN based materials have physical and electronic properties that make them attractive for high temperature, high power and high frequency devices. Wide bandgap semiconductors (GaN and SiC) have inherently lower thermal carrier generation rates and higher breakdown fields compared to Si and GaAs, as shown in Table 1. GaN has additional advantages including a high mobility and a high electron velocity. Furthermore, high electron mobility transistors (HEMTs) which offer higher mobilities, better charge confinement and higher breakdown voltages can be fabricated in the AlGaN/GaN materials system. Room temperature RF (8-10 GHz) output powers on the order of 6-8 W/mm are theoretically possible in the AlGaN/GaN materials system and power densities as high as 6.8 W/mm have recently been reported [1].

While promising output powers have been reported in AlGaN/GaN HEMTs, materials-related issues continue to limit device performance. Persistent photoconductivity (PPC) and drain I-V collapse have been reported in AlGaN alloys [2] and AlGaN/GaN heterostructures [3]. These effects arise from carrier trapping and generation from deep levels in the material and can lead to poor high frequency performance, decreased drain

[1] S.T. Sheppard, et al., 56th Device Research Conference, Charlottesville, VA, June 22-24, 1998.

[2] M.D. McCluskey, N.M. Johnson, C.G Van De Walle, D.P. Bour, M. Kneissl and W. Walukiewicz, Mat. Res. Soc. Symp. Proc. 521 (1998) 531.

[3] J.Z. Li, J.Y. Lin, H.X. Jiang, M. A. Khan and Q. Chen, J. Appl. Phys. 82 (1997) 1227.

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currents and reduced output powers in a HEMT. PPC and current collapse in GaAs-based HEMTs have been attributed to defect-donor complexes (DX centers) in $Al_xGa_{1-x}As$ when x>0.20. Evidence for oxygen DX-centers in Al-rich $Al_xGa_{1-x}N$ (x>0.27) has recently been reported [2]. High Al content AlGaN layers (x>0.20) are commonly used to achieve high sheet densities in AlGaN/GaN HEMT structures via piezoelectric-induced doping as shown in Figure 1. In order to further improve the performance of III-V nitride HEMTs, methods must be identified to reduce or eliminate the deleterious effects of deep level defects that result from the use of high Al composition layers.

Table 1. Properties of candidate materials for high power, high temperature, high frequency electronic devices.

	Si	GaAs	4H-SiC	GaN
Bandgap (eV)	1.1	1.4	3.3	3.4
Breakdown field (10^5 V/cm)	2	4	30	30?
Electron mobility (cm^2/Vs)	1400	8500	800	900^a,2000^b
Maximum velocity (10^7 cm/s)	1	2	2	3
Thermal conductivity (W/cm K)	1.5	0.5	4.9	1.3

a) For n=5E16 cm^{-3}

b) For an AlGaN/GaN structure

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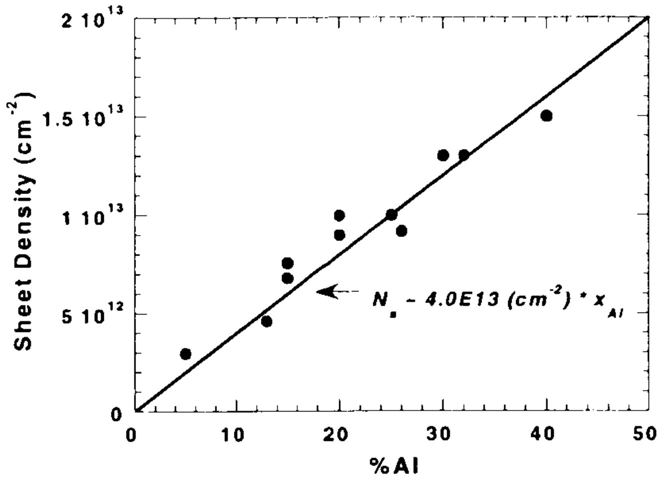

Figure 1. Sheet density versus % Al in undoped 23 nm AlGaN/GaN heterostructures. Piezoelectric-induced doping results in an increase in sheet density with increasing Al composition.

(2) Describe clearly the INVENTION, RESULTS, ADVANTAGES. (Make DRAWINGS when possible and DESCRIBE FULLY the invention and its OPERATION using REFERENCE NUMERALS to indicate elements.

In this disclosure, we describe a technique to improve the performance of GaN-based HEMTs through the use of InGaN alloys in the channel layer of the device. InGaN has a larger a-lattice constant than GaN, consequently lower Al composition AlGaN layers can be used to achieve comparable levels of strain and piezoelectric doping as AlGaN/GaN heterostrucutres. As a result of the large a-lattice constant difference between GaN and InN (0.351Å) compared to GaN and AlN (0.079Å), low Al and In content layers can be used to produce pseudomorphic AlGaN/InGaN heterostructures with comparable strain to

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AlGaN/GaN. For example, the lattice mismatch of an $Al_{0.10}Ga_{0.90}N/In_{0.046}Ga_{0.954}N$ interface is identical to that of $Al_{0.30}Ga_{0.70}N/GaN$. Consequently, it should be possible to produce AlGaN/InGaN heterostructures that enable the use of reduced Al content AlGaN layers without significant reductions in piezoelectric-induced doping or degradation of the structural or electrical properties of the channel layer. In addition to a reduction in DX-center related transient effects, the use of low Al content AlGaN layers in the HEMT may also yield reduced ohmic contact resistance.

The electron mobility of InN is also significantly higher than in GaN (4000 cm^2/Vs for n=1E16 cm^{-3}) [4]. Consequently, the use of InGaN in the channel layer of the device should lead to additional improvements in electrical properties and device performance.

Figure 2 contains a simple schematic of a potential AlGaN/InGaN HEMT structure. In this case, a pseudomorphic AlGaN layer is grown on top of an InGaN layer on an intial GaN layer. The InGaN layer should be thick enough so that it is relaxed. Alternatively, the InGaN layer can be grown directly on the substrate (including a buffer layer). The AlGaN layer can be undoped or the top most portion of the AlGaN can be doped to further increase the sheet density. Alternatively, an InGaN channel HEMT can be fabricated using GaN or InGaN on InGaN. In this case, chemically reactive Al-containing layers are completely eliminated from the device structure. A GaN/InGaN HEMT may have better long-term stability and reliability under high power operation than an AlGaN/GaN or AlGaN/InGaN HEMT device. Furthermore, an InGaN/InGaN HEMT may prove easiest to implement due to the differing optimum growth conditions between InGaN and AlGaN or GaN.

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[4] T.L. Tansley and C.P. Foley, Electron. Lett. **20** (1984) 1066.

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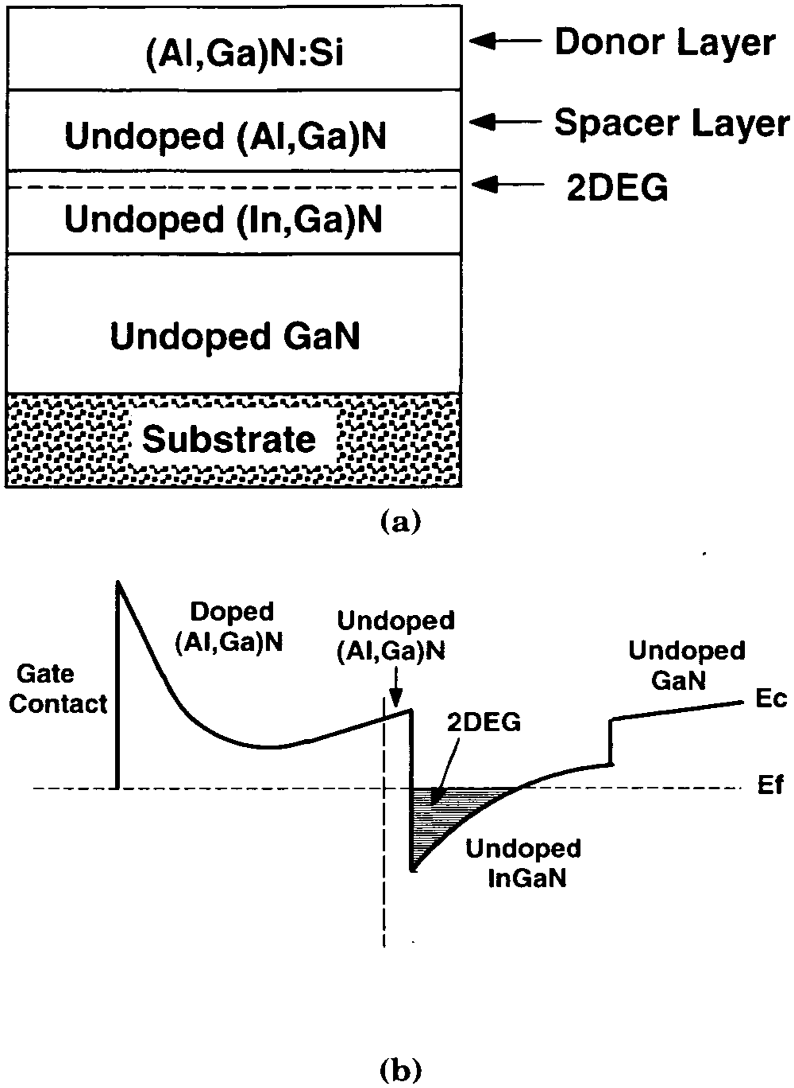

Figure 2. Schematic (a) and band diagram (b) of an AlGaN/InGaN HEMT structure.

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(3) Was this invention first conceived or first actually reduced to practice under government contract support? If so, what are the contract name and contract number?

No.

(4) Has there been any publication, public disclosure, or offer for sale, or are any contemplated? Provide details, especially dates.

The idea of using InGaN in the channel layer of a GaN-based HEMT was included in a Phase I SBIR submitted to BMDO in January, 1997. The sections on InGaN in that proposal were marked as proprietary.

(5) Laboratory Notebook or Runsheet Number cross reference, including date(s).

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APPENDIX B

DEPARTMENT OF THE AIR FORCE
WRIGHT LABORATORY (AFMC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

25 February 1997

MEMORANDUM FOR: ADVANCED TECHNOLOGY MATERIALS, INC.
ATTN: DANIEL SHARKEY
7 COMMERCE DRIVE
DANBURY CT 06810-4169

FROM: WL/AAOP Bldg. 620
2241 Avionics Circle Ste. 18
Wright-Patterson AFB, OH 45433-7320

SUBJECT: Air Force Small Business Innovation Research (SBIR) Program DOD Solicitation 97.1

CONTROL NO.: 97WAA-272

1. Please be advised that your proposal, entitled "InGaN Channel MODFET for Microwave Power Applications," submitted to the Avionics Directorate in response to Topic No. AF97-124 of the subject solicitation, has not been selected for funding.

2. The SBIR program is extremely competitive. This year, the Avionics Directorate received 375 proposals in response to 26 topics. We have selected 37 proposals for funding.

3. Thank you for your participation in the Air Force SBIR Program. We encourage you to continue to submit proposals under future SBIR Solicitations.

Sharon A. Gibbons
SHARON A. GIBBONS
SBIR Program Manager
Avionics Directorate

APPENDIX C

UNITED STATES PATENT APPLICATION

OF

JOAN M. REDWING
EDWIN L. PINER

FOR

INDIUM GALLIUM NITRIDE CHANNEL HIGH ELECTRON MOBILITY TRANSISTORS, AND METHOD OF MAKING THE SAME

GOVERNMENT RIGHTS IN INVENTION

The invention was made in the performance of the U.S. Army Space and Missile Defense Command, Contract Number DASG60-98-C-0025. The government has certain rights in the invention.